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THE DETERMINATION OF THE OPERATING RANGE OF A TWIN-GRIP CONTROL YOKE THROUGH BIOMECHANICAL MEANS

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Summary

A twin-grip control yoke was designed as an ergonomic case study that allows dual axis control inputs, both axes being rotational. Inputs are effected by rotating the grips. It will be reported how the handles were designed with respect to their shape and size and how the angular range of the control yoke in both rotational axes was evaluated.

The hand grip design is based on the anthropometric data of the hand. The main parameters for the layout are the breadth of the hand, the grip circumference, and the thumb length. The steering task for which the control yoke is designed requires that the grip shape takes into account task relevant grip characteristics, such as a rest for hand and thumb as well as a thumb operated switch button. One of the design requirements is the full use of the available motion range for steering inputs in the two rotational axes which is limited by the human arm-hand-system.

Using EMG activities, which were measured at the forearm, the permissible pitch and roll angles of the control yoke were evaluated to be $\pm 30^{\circ}$. The limitation stems exclusively from the combined limits of the radial and ulnar ranges of abduction of the human wrist joint. It should be pointed out that in this study the control range was not limited by muscle fatigue which is also measurable with EMG but rather by EMG levels which avoid painful loads on tendon and ligament structures. The experimental series is based on an isotonic rotation in both axes. EMG activities were only measurable under extreme angles of deflection. If the operator has to deflect the control element from its neutral position against a spring resistance a further reduction of the operational range will be expected.

Introduction

In this study, a control yoke which requires two-hand operation was tested to determine its operating ranges. The intention of this investigation was to find out the optimal form of the control yoke and the maximum permissible operating range in both rotating axes. In these experiments controls had no spring resistance. Future studies will involve controls with spring resistance.

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The control yoke has two rotating axes. Vehicle direction changes to the left or right are accomplished by turning the yoke as with a steering wheel of an automobile, called here roll motion. Vertical vehicle direction changes are accomplished by rotating the yoke handles towards or away from the operator which will be called pitch motion.

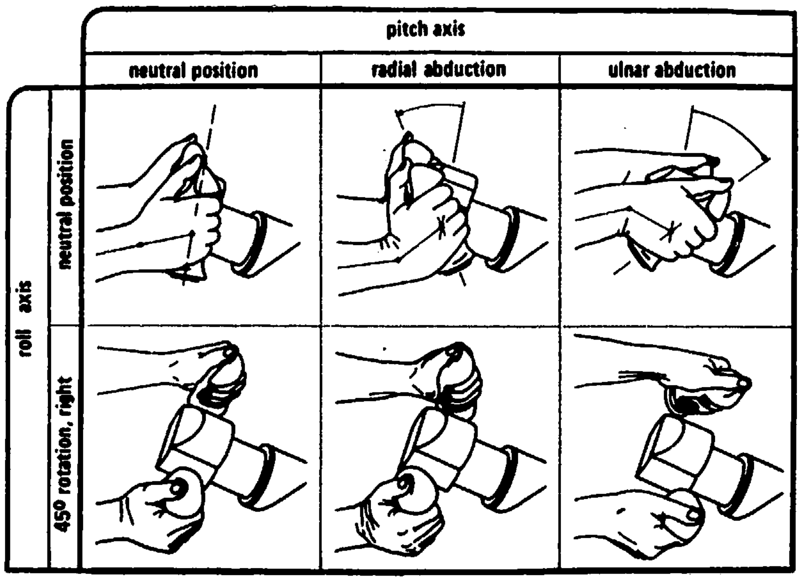

Figure 1 : Influence of roll axis rotation of a twin grip control yoke on radial and ulnar abduction angles of both hands

In the left of the upper row of figure 1 is to be seen the neutral position and in the middle and right pictures of this row the extreme excursion during the pitch movement. These two pictures illustrate the biomechanical position limits of the hand when rotating the yoke towards and away from the operator. The pitch motion of the hand towards the operator is accomplished by radial abduction; pitch motion away from the operator is accomplished by ulnar abduction. Similar hand positions are shown in the lower row of pictures with a 45° roll angle position coupled with neutral, radial and ulnar pitch abduction.

With 0° pitch angle and roll motion to the right, radial pre-abduction will have occured in the right hand and some ulnar pre-abduction in the left hand, thereby restricting the available amount of further abduction for pitch command purposes. It can be shown that with increases in roll motion to the right pre-abduction will increase until biomechanical limitations make pitch commands impossible or very difficult. Similar pre-abduction occurs with left roll motions.

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Biomechanical consideration of the arm-hand-system

Figure 2 illustrates the abduction range of the hand. In the left part of the picture there is shown a hand in two positions holding a stick. The hand rotates by an assumed axis of rotation through the wrist joint, as indicated by a small circle. This hand, turned 8 to 12°, corresponds to the normal resting position of the human hand.

If the prolonged center line of the forearm is considered as the reference line a natural pre-abduction of the hand can be noticed. The values given in the literature [e.g. 1] for the ulnar and radial abduction of the hand are based on this resting position. There is obviously no relationship between the angle at which the hand is in the natural resting position and the maximum range of abduction of the 5th to 95th percentile. On the right part of the figure the angle range is shown for the radial abduction with 35° and for the ulnar abduction with 53° measured from the resting position of the hand. This abduction angle of 88° is equivalent to the 90th percentile.

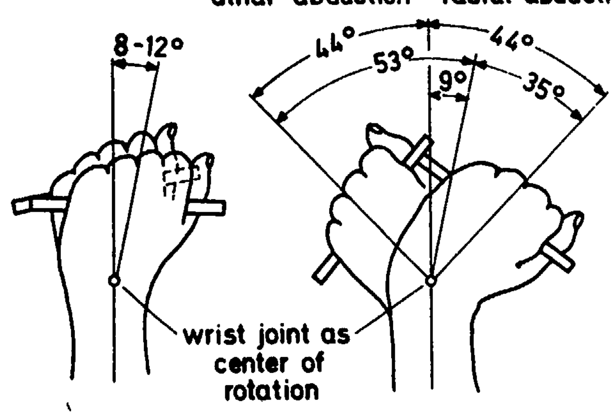

Figure 2 : Abduction range of the hand

If 9° is subtracted, which corresponds to the natural pre-abduction from the range of the ulnar abduction, a value of 44° both for the ulnar and for the radial angular range will be obtained. This consideration is important for practical applications in so far as there should be the same angular range in radial as in ulnar direction for the pitch movement, i.e. the up and down maneuver of the vehicle. If the total abduction ability of the hand is used for turning a control yoke, two rotational axes can be selected. These two rotational axes of the control yoke cross in the steering column. In figure 3 the case is shown where the rotational axis of the wrist joint is equal to the axis of the control element. Consequently, there is hardly any motion of the forearm. The total range of abduction is used as pitch angle range, that is for radial abduction of 35° and for ulnar abduction of 53°, measured from the resting position. There is a light disadvantage of forearm movement when the rotational axis of the wrist joint does not correspond with the rotational axis of the hand grip for small and large hands. This effect does not occur if the rotational

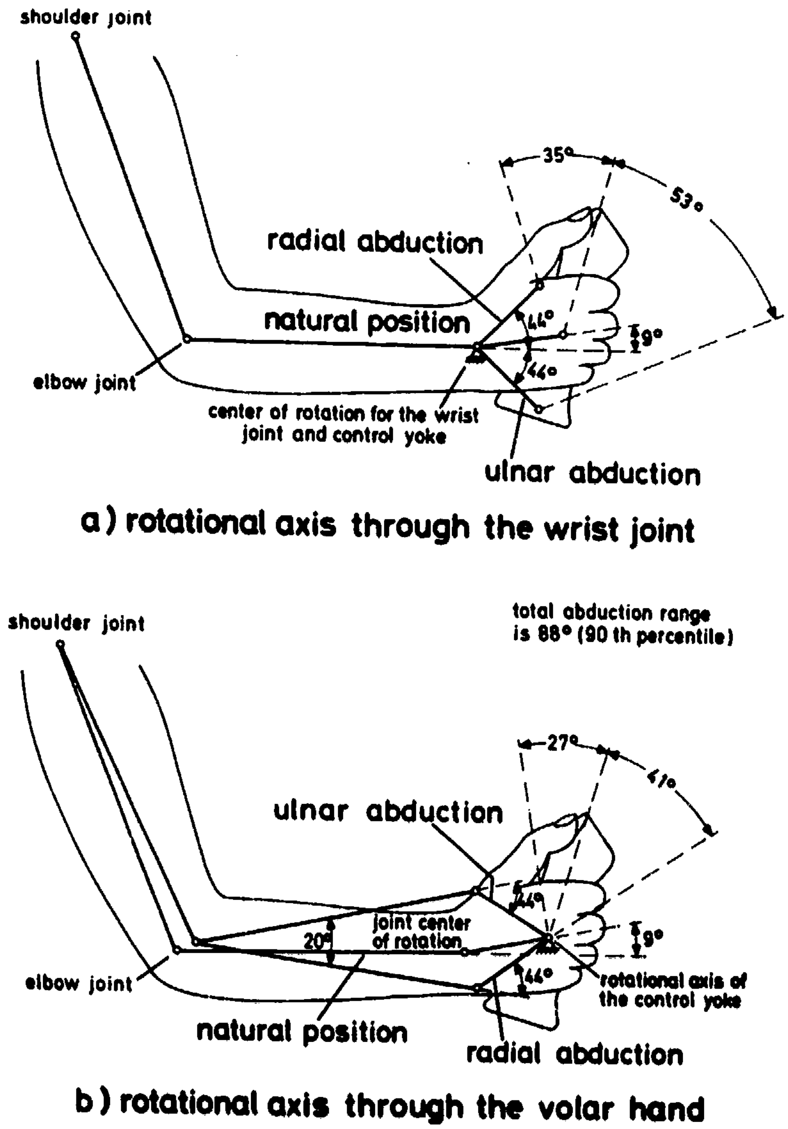

Figure 3 : The range of forearm motion for different rotational axes of the control yoke

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axis of the hand grip corresponds with the center of the hand volar or palm as shown in the picture below. A pronounced up and down movement of the forearm which results during ulnar and radial abduction is illustrated in figure 3. Though, radial and ulnar abduction come to their limits at 88° for the maximal abduction of the 90th percentile, the maneuvering pitch angle range only reaches 68°, e.g. 27° for radial and 41° for ulnar abductions from the resting position.

Anthropometrical Design of the control grip

Figure 4 shows the operator sitting in front of the control console. The angle of inclination with respect to the body will be selected in a way so that the arm-hand-system of a 50th percentile operator measured from the shoulder reference point is in a position to turn the control yoke with the same angular values in ulnar and radial direction. A control yoke is shown, the rotational axis of which goes through the volar hand.

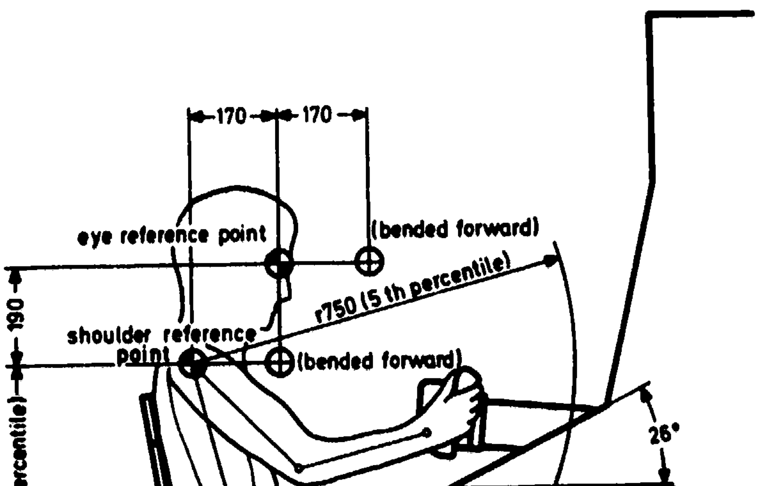

Figure 4 : Suggested anthropometric parameters for seated operator console

The control task for which the control yoke was designed requires a specially shaped grip which takes into account task relevant grip characteristics, such as a hand and a thumb rest and a switch button that is thumb operated (figure 5). The design of the grip was based on the 95th percentile hand. The dimension A of the palm was based on hand width. The hand fits between the hand rest and the top section of the grip. The fingers span the grip slantwise to the longitudinal axis of the grip and not in parallel fashion as they would with a cone.

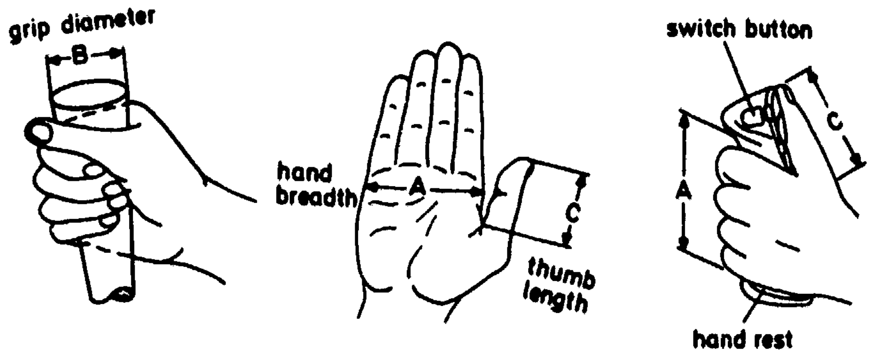

Figure 5 : Anthropometric parameters for designing a handgrip

So long as the switch button is not used, the operator can smoothly move his hands with the control yoke and follows its motions. Under these working conditions the hand of the 95th percentile man is resting on the hand support and the thumb is on its thumb rest. Smaller hands such as the 50th or 5th percentile hands can use either the hand rest or the thumb rest as a basic working position during the control task.

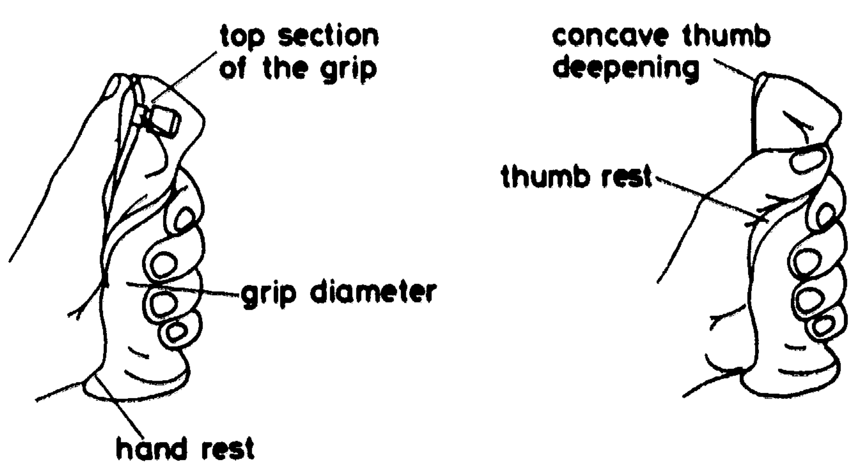

Figure 6 : Anthropometric parameters for designing a handgrip

The basic dimensions of the grip are the dimensions of an ideal conical bar which was first used by Henning. Henning suggests an increase in radius by 5 mm for each 80 mm in length. The grip is finger parallel and the forearm axis is vertical to the cone axis. The circumference is about 150 mm for a 95th percentile hand. As can be seen from the left picture of figure 6 the finger tips touch lightly the opposite part of the hand and the thumb rests on parts of the pointing finger. If the cone is closed the fingers are inclined to the longitudinal axis of the cone. A grip was designed using finger indentation and an appropriate deviation of the cone shape as may be seen in figure 5.

With this grip the finger tips of the 95th percentile hand are at small but constant distance from the opposite part of the hand. For the smaller hands like 50th or 5th percentile hands this distance becomes larger but still guaranties a good form closure. With this design a larger thumb rest was used which results in a separation of the possible touch between the thumb and the fingers. The location of a switch button in the grip head was based on the thumb length of the 50th percentile hand. Thumbs which are longer and shorter than 50th percentile are still in position to operate the switch button by use of lower or upper parts of the thumb respectively. A concave depression in the top section of the grip allows sufficient motion for larger thumbs when pressing the switch.

Biomechanical determination of the operating range of the twin-grip control yoke

For the layout of a control yoke both anthropometric and biomechanic qualities of the human hand-arm system must be considered. A method is proposed in this paper which permits a determination of a biomechanical range on the basis of surface electromyography activities which are involved in movement and force exertion. At the limits of movement, rather high EMG activity occurs together with such consequences as muscle, tendon, or ligament strain and/or pain.

For EMG measurements, subjects were instructed to grip the yoke lightly with both hands so that no forearm muscles were contracted. For each selected roll angle position of the yoke, the control was then slowly moved through both pitch directions. Raw EMG signals were processed with a double wave rectifier and a special averaging filter [2, 3, 4] .

EMG activity for the right hand in a number of different roll angle positions are illustrated in figure 7 as a function of pitch angles for roll angles in the right direction. The curves illustrated are only for EMG values recorded during increasing pitch angles as these represent the worst case for control evaluation.

The upper EMG value of "1" unit was arbitrarily given to the EMG level obtained when wrist joint pain was experienced after repeatedly holding an angle position for a few seconds. The maximum value of the curves (approx. .75 units) is obtained at the maximum pitch angle which was measured. The maximum pitch angle

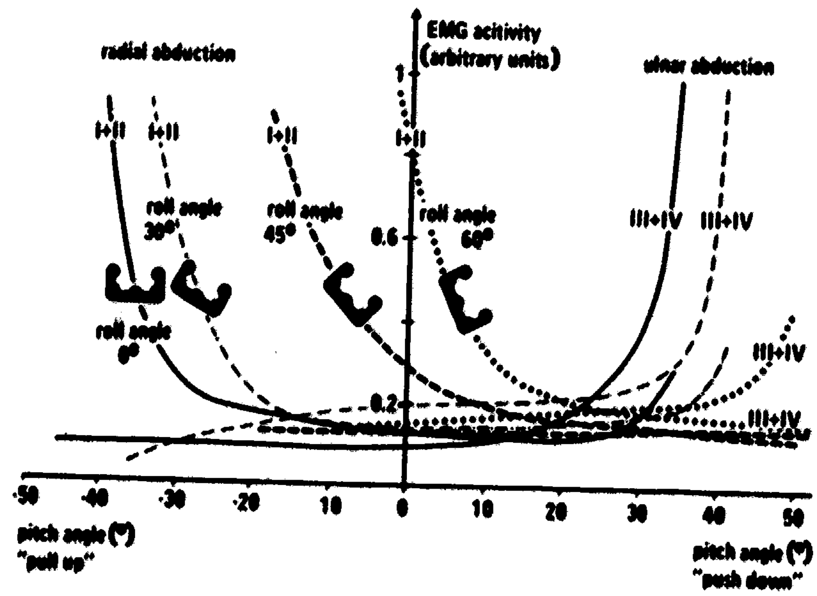

Figure 7 : EMG activities of radial and ulnar abductors of a right hand with 90th percentile wrist movement range as a function of pitch angle for various roll angles. Roll movement is in right

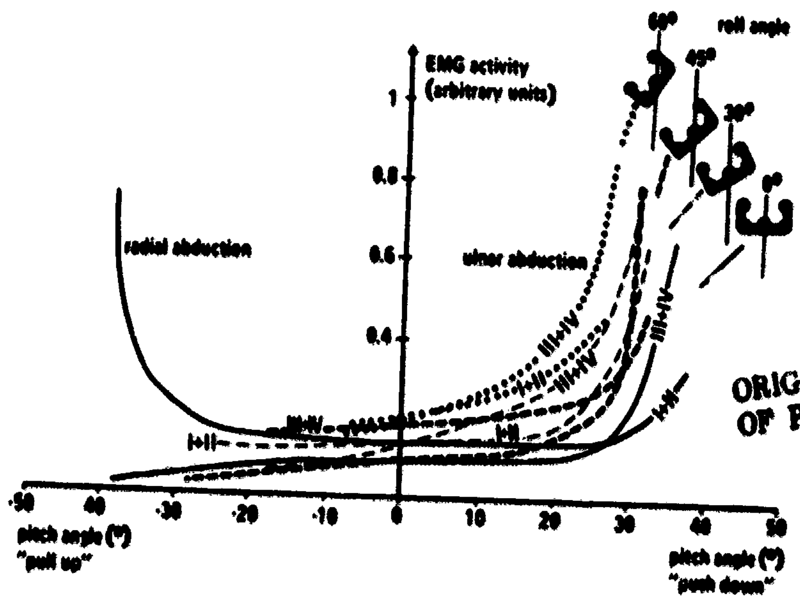

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Figure 8 : EMG activities of radial and ulnar abductors of a right hand with 90th percentile wrist movement range as a function of pitch angle for various roll angles. Roll movement is in left

measured was selected after experimentally determining the maximum pitch angle at which no wrist pain build-up occured during fairly long measuring sessions. For any given pitch angle there is a tendency for pre-abduction to be larger with larger constant roll angles. It can be seen that at 0° roll angle the full range of possible wirst movement of the subject can be used for pitch commands in both directions because there is no pre-abduction. At 60° roll angle to the right, radial pre-abduction is so large that no pitch angle movement in this "pull up" direction is possible. In the right side of the figure the EMG curves for ulnar abduction i.e. in the "push down" direction is illustrated. The 45° and 60° roll angle permit relatively large "pull up" commands although the curves do not rise as high as those for radial abduction on the left side of the figure. The reason for this is that ulnar abduction of the left hand, which is not illustrated, reaches a limit at these pitch angles before the right hand, thereby preventing further ulnar abduction of the right hand. Of course, release of the control by the left hand would have permitted further movement.

EMG values for ulnar and radial abduction of the right hand is shown in figure 8 for left roll at various roll angles. As can be seen on the left side of the figure for left roll, right hand "pull-up" pitch commands or radial abduction movement is so severely limited by radial pre-abduction of the left hand in all roll angle positions except 0° that further movements are not possible. The range of ulnar abduction or "push-down" commands illustrated on the right side of the figure is slightly reduced by ulnar pre-abduction thereby allowing considerable movement before the ulnar abduction limits are reached.

Discussion of the EMG-measurements

In designing a range for this control device the following points are the most important to consider. 1. It should permit the largest possible pitch angle in both directions for each of the largest possible roll angles for subjects with 5th percentile wrist movement ranges. 2. Only lower levels of EMG activity should occur most of the time during control operations. Moderate EMG activity levels should occur very briefly and no high EMG activity at all.

As can be noticed in the figure 7 and 8 these requirements can be satisfied for the subject tested with roll and pitch angle ranges of approx. $\pm 30^{\circ}$ each (at which no more than 0,5 units of EMG activity are reached). It should be pointed out that in this study the control range was not determined by muscle fatigue limits which are also measurable with EMG but rather by EMG levels which avoid painful loads on tendon and ligament structures. The EMG measuring method presented proved to be a valuable objective aid for determining an advantageous control range.

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